(12) UK Patent Application (19) GB (11) 2 131 887 A

(21) Application No **8332795**
(22) Date of filing **8 Dec 1983**
(30) Priority data
(31) **824226**
(32) **8 Dec 1982**
(33) **Finland (FI)**
(43) Application published **27 Jun 1984**
(51) **INT CL^3 F03B 13/12**
(52) Domestic classification **F1S** 28B1 28B2
(56) Documents cited **GB 2037899A GB 2003993A GB 1587344**
(58) Field of search **F1S**

(71) Applicants
KG Inventions Ltd Oy (Finland)
Kaarinan kunta
20780 Kaarina
Finland

(72) Inventor
Klas Gardberg

(74) Agent and/or Address for Service
Frank B. Dehn & Co.,
Imperial House,
15/19 Kingsway,
London WC2B 6UZ

(54) Wave energy conversion unit

(57) The unit comprises a conversion device attached to a frame movably and reacting to the waves so as to utilize the kinetic energy of the waves by converting the said energy to a high-pressure fluid for driving a turbine operating as the central machinery of the wave-energy power plant system. The conversion device comprises a supporting carriage 2 movable horizontally relative to the frame 11, 16, a pontoon construction 1 connected to the supporting carriage and moving along with the wave movement, locking means 9 for locking the pontoon construction 1 in the highest and lowest positions reached by it along with the wave in the vertical direction and for releasing it again after the wave crest/trough has moved forwards so that the pontoon construction is then almost completely above/below the water surface, and single-acting or double-acting high-pressure fluid pumps 12 connected to the pontoon construction, for converting the energy of the free movement of the pontoon construction to hydraulic pressure.

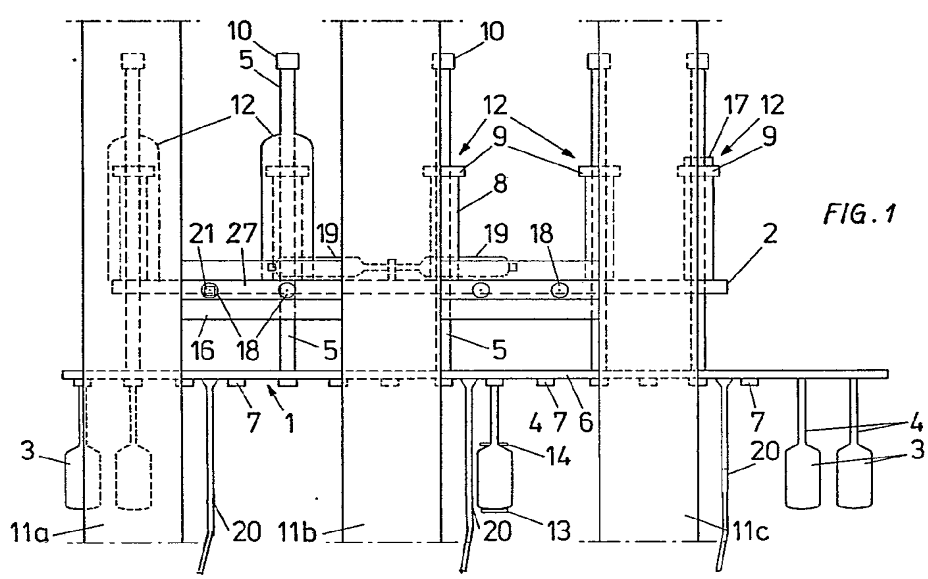

FIG. 1

GB 2 131 887 A

2131887

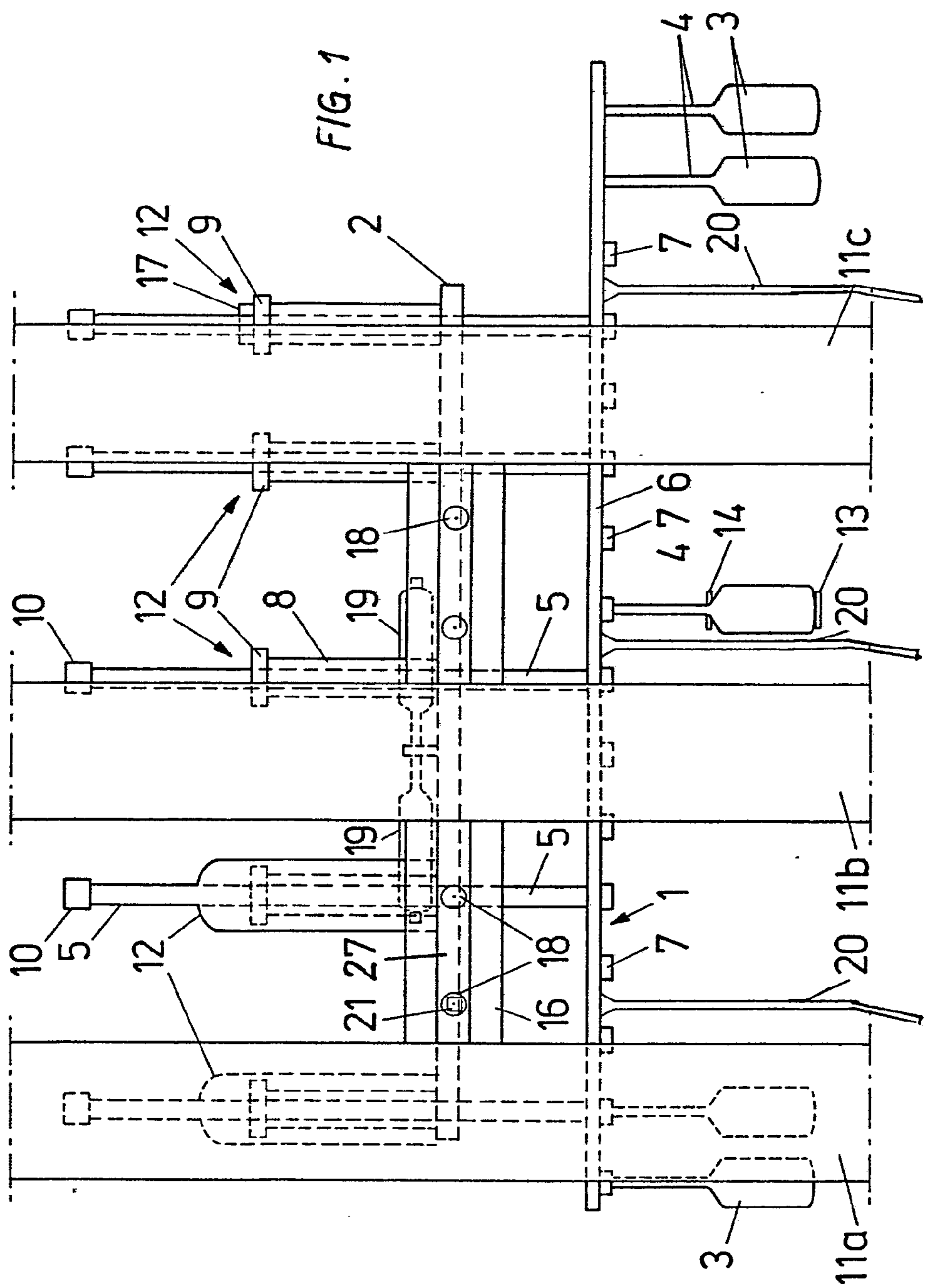

FIG. 1

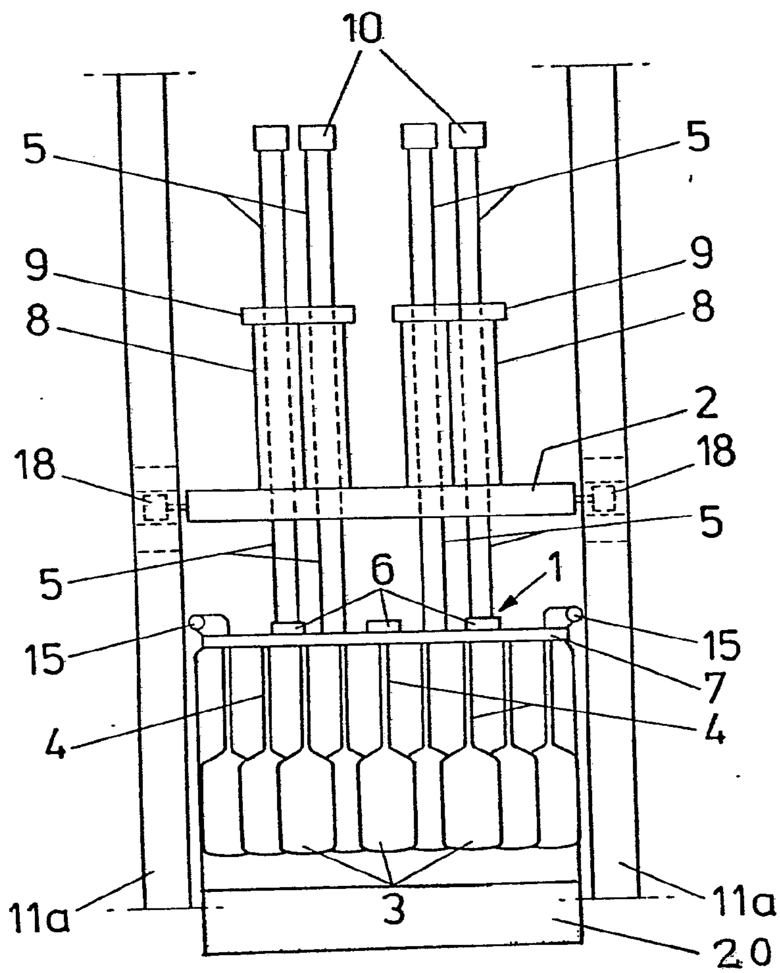

FIG. 2

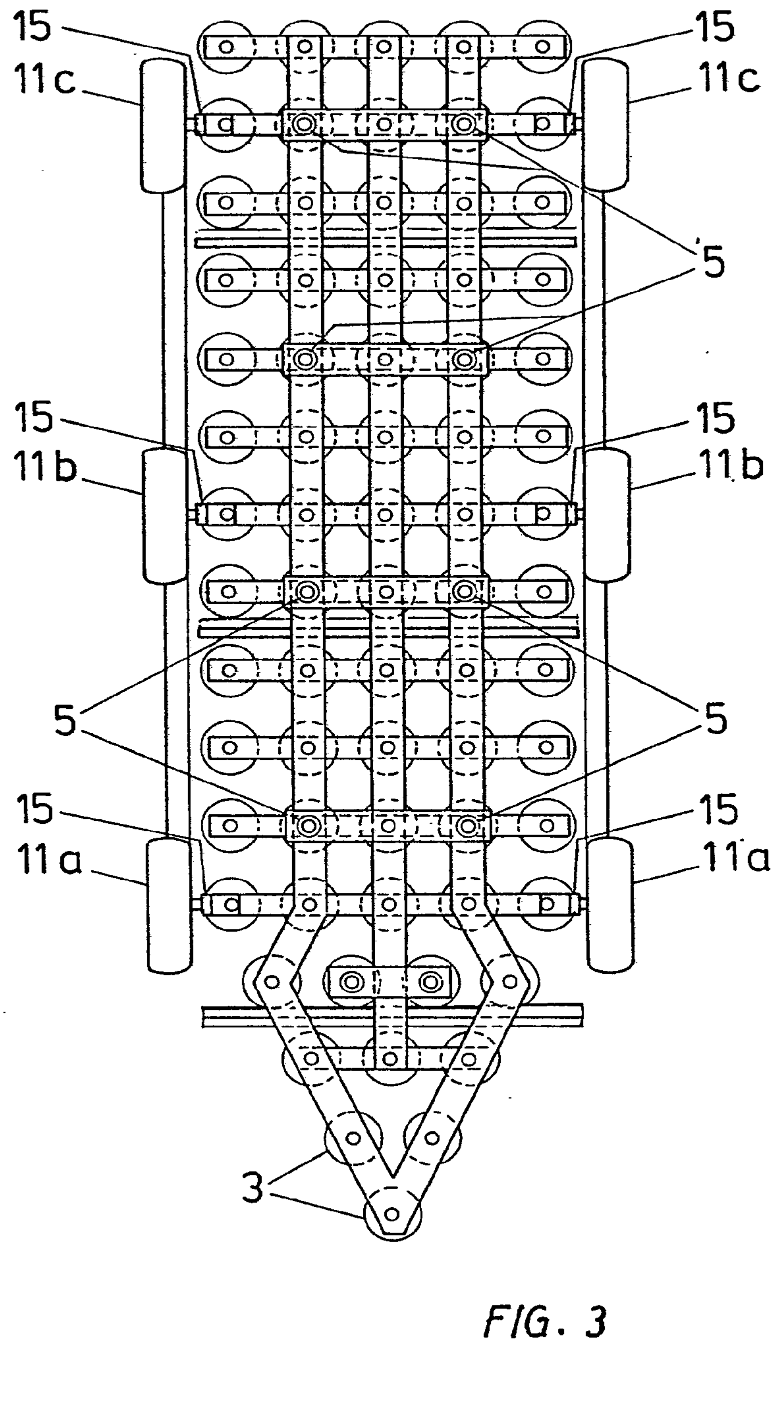

FIG. 3

SPECIFICATION

Wave energy conversion unit

The present invention is concerned with a wave energy conversion unit, which comprises a frame and a conversion device movably attached to the frame for reacting to waves so as to utilize the kinetic energy of the waves by transferring the said energy to a high-pressure fluid driving a turbine, for example a Pelton turbine, operating as the central machinery of the wave-energy power plant system.

After solar and wind energy, wave energy is the greatest pure, renewable energy form, whose potential within ice-free sea areas has been estimated at about 50 TW. Methods aimed at utilization of wave power have been suggested ever since the 19th century, and in particular in recent years great attention has been paid to research into wave energy. Among the solutions that have been suggested should be mentioned the cell converter of Prof. Rolf Törnqvist, the swinging wing of Salter, and many suggestions based on bending movement. So far, however, owing to constructional problems and/or low efficiency, among these solutions, there has not emerged a solution that differs from the others clearly advantageously and that has thereby gained extensive use.

The energy of a sea wave is, in principle, distributed uniformly over its entire wavelength, whereat the power P in, for example waves of wavelength L = 180m, height H = 4.5m, and period T = 10 s, is 250 kW per metre of the wave front ($P_{1m} = 0.92 \times \sqrt{L} \times H^2$). Thus, the energy content of one cycle of the example wave is 2,500 kWs, i.e. 13.88 kWs/m^2.

This is, however, only a value indicating the average energy content of a cycle. As a matter of fact, at each metre of length of a wave, during a cycle, two accumulations of energy occur: at the crest of the wave, the movement of water in the vertical direction is zero, so that, underneath a surface square metre placed at the wave crest, there is a water column of which the top portion H/2 = 2.25m is placed above the average surface level. Its static energy is 2,250 kg x 2.25/2 m = 2,531 kgm, which is, thus, as a whole concentrated in the portion of the water column placed above the surface level. As the velocity of movement of the portion above the surface level in the horizontal direction is, on the average, 1.1 m/s, corresponding to an energy quantity of 139 kgm, its overall energy content is consequently 2,670 kgm, i.e. 26.18 kWs/m^2. At the trough of the wave, the situation is the same.

If the portion placed above the surface level were allowed to fall freely to the surface level, it would attain a velocity of 4.7 m/s in 0.75 seconds, the friction and the resistance accompanying displacement not being taken into account. In practice, a falling velocity of 1.29 m/s is reached in 2.22 seconds, whereat T/4 = 2.5 s; the lower value results from the inclination of the path of movement of the particles of water, of a shape of a relatively circular ellipse, angled by about 30° in the direction of the wind. Under these circumstances, it has been left with only about 1/13 of its static energy, the overwhelming majority of the said energy being consumed for accelerating the underlying water masses both upwards and downwards, when the wave height becomes lower, also laterally.

Thus, the sequence of events is as follows: the wave crest is generated by the joint effect of the kinetic energies of the large water masses placed underneath as well as in front of and behind the wave crest. A wave trough is generated correspondingly when the force of gravity makes the wave crest collapse, the water masses in the wave crest, owing to the moments of inertia of the underlying layers, largely spreading forwards and rearwards and, owing to the horizontal component of movement obtained by them in this way, generating a wide depression in the water surface. The momentary negative pressure caused by the depression and the resulting masses of water seeking their way into the said depression from ahead and from the rear, when meeting, generate a new crest of wave, etc. Moreover, owing to the pressure of the wind, the wave crest additionally has a rather strong horizontal component of movement in the direction of the wind, and the wave trough has a compensating current in the opposite direction.

Since the static energy of the wave is so strongly concentrated in its surface layer, a remarkable quantity of static energy could be recovered by maintaining a certain volumetric proportion of the wave crest in its position until the rest of the wave crest has moved forwards. In this case this static energy would not be available to the surface level only, but down to the following wave trough.

In accordance with the present invention there is provided an energy conversion unit for a wave-energy power plant, comprising a frame and a conversion device movably attached to the frame for reacting to waves, wherein the conversion device comprises a supporting carriage arranged for movement horizontally relative to the frame, a pontoon construction connected to the supporting carriage for movement along with the wave movement, locking means for locking the pontoon construction in the highest and lowest positions reached by it along with the wave in the vertical direction and for releasing it again after the wave crest/trough has moved forwards so that the pontoon construction is then almost completely above/below the water surface, and single-acting or double-acting high-pressure fluid pumps connected to the pontoon construction, for converting the energy of the free movement of the pontoon construction to hydraulic pressure.

The carrying part of the pontoon construction preferably comprises several vertical cylindrical containers shaped slightly hydrodynamically at both their ends. The mass of the pontoon construction is preferably approximately one half or slightly less than one half of the mass of the quantity of water displaced by its containers when fully submerged.

In use of embodiments in accordance with the invention, the appropriately dimensioned and shaped pontoon, having risen onto the wave crest/sunk to the wave trough, is stopped at its extreme position until it may, after the wave crest/trough has moved sufficiently forwards, freely drop/rise almost with its full weight/lifting force.

As can be seen there is provided a wave energy

conversion unit that operates in accordance with the above, that has a very robust construction and high efficiency, and that is reliable in operation.

An embodiment of the invention will now be described by way of example and with reference to the attached drawings, in which:

Figure 1 is a schematical side view of an exemplifying embodiment of a wave energy conversion unit in accordance with the invention,

Figure 2 shows the unit of Fig. 1 as viewed from the front, and

Figure 3 is a top view of the unit of Fig. 1 with the supporting carriage removed.

Figures 1 to 3 illustrate a more detailed construction of an embodiment of the wave energy conversion unit, illustrated somewhat schematically. The part of the unit actually reacting to the waves is the pontoon construction 1, which consists of longitudinal and transverse beams 6 and 7 placed crosswise relative to each other and rather far apart, of hydrodynamically shaped containers 3 attached to the beams by intermediate arms 4, and of control and support bars 5. The support bars 5 connect the pontoon construction to the supporting carriage 2 placed above the pontoon construction. The supporting carriage 2 is placed between pairs of columns 11a, 11b, 11c, and so on supported or anchored in some other way. Between the columns 11a, 11b and 11c, bridges 16 have been attached, inside which closed grooves 27 have been formed, in which hard-rubber wheels 18 journalled to the supporting carriage 2 move, the number of the said wheels being for example four pairs. In this way, the supporting carriage may move in the horizontal direction relative to the columns 11a, 11b and 11c. This horizontal movement is limited and utilized by two single-acting high-pressure fluid pumps 19 placed between the middle column 11b and the supporting carriage.

The guide and support bars 5 connected to the pontoon construction pass through the supporting carriage 2 and through guide sleeves 8 placed on the top face of the said carriage. The top ends of the guide sleeves 8 are provided with, locking means 9 for example magnetic locking means for locking the pontoon construction at the desired level. The movement of the pontoon construction is limited and utilized by high-pressure fluid pumps 12, always provided there is one pump per one pair of support bars, as well as by expansions 10 formed at the ends of the bars 5. The pontoon construction is also provided with intermediate flanges 20, which prevent horizontal movement of water in the pontoon construction, whereas the positioning of the cylinders 3 permits vertical movement of water. Besides by the guide and support bars 5, the movement of the pontoon construction upwards and downwards is also guided by rubber wheels 15 attached to the sides of the pontoon construction and supported against the columns 11a, 11b and 11c, the wheels being provided with spring suspension if necessary.

The function of the supporting carriage 2 is to guide the movement of the pontoon construction 1 in the vertical direction and to keep it in position in its extreme positions, while at the same time permitting resilient movement of the entire equipment in the direction of the horizontal component of the waves. Thus, the said carriage is alternatingly burdened by the weight of the entire pontoon construction and by its entire lifting force.

In order to permit the performance of the different stages of the operation of the wave energy conversion unit, the opposite ends of at least one cylinder 3 are provided with detectors 13 and 14, which give an impulse for temporary elimination of the counterpressure of the high-pressure fluid pumps 12 in order to give the pontoon construction a residual acceleration as the containers 3 reach contact with the water surface. The locking pulse is given to the locking means by a detector 17 reacting to the stopping of the rising and lowering movement of the pontoon construction, the said detector 17 being connected, e.g., to some locking means 9. The releasing pulse to the locking means 9 is given by a detector 21, connected, e.g., to the last pair of wheels 18 in the direction of the wave movement, which detector 21 acts on the basis of the axle load or axle deflection when the strain reaches the preset value.

One such wave energy conversion unit of a wave-energy power plant operates independently from any neighbouring modules as follows: When the pontoon construction 1 reaches its top level about 24° after the peak of the wave crest, the sensor 17 gives a locking impulse to the locking means 9. The pontoon construction 1 remains in this position until the carrying force of the water, with the approach of the wave trough, has been reduced to substantially 6 to 10% of its maximum value. Thereat, the increasing axle load of the rear support wheels 18 activates the sensor 21, which gives an impulse to the locking means 9 and releases the pontoon construction. The release impulse may be given in advance, for owing to the low residual acceleration, the movement of the pontoon construction is initially quite slow, and the water surface, which is at this stage moving down rapidly, leaves it instantly completely free. An advance larger than that mentioned above is, however, not possible, because the counter-pressure in the high-pressure fluid pumps 12 would, in such a case, tend to raise the pontoon construction. The required residual acceleration of about 0.051 g now gives the pontoon construction a final velocity of 1.53 m/s when it strikes against the wave trough. Owing to its cellular structure, it continues its movement while the quantity of water displaced by it raises the water surface in excess of the rise in accordance with the wave. In the example, the area free for water in the pontoon construction is equal to the area of the containers, so that the excessive rise in the water surface is equal to the depth of penetration of the pontoon into the water. An increase in the free area would make the pontoon construction unreasonably longer, in which case its peripheral portions would meet the water surface substantially earlier than the middle portion would.

If the pontoon construction 1 is allowed to go on working after contact with the water surface, it stops after it has progressed 0.4 m, in which case the starting point for the next rising step remains quite unfavourable. On the contrary, if the counter-pressure caused by the high-pressure fluid pumps 12 is eliminated by means of an impulse given by the sensors 13 and 14

on contact taking place with the water surface and the pontoon construction is allowed to continue its movement freely, it is not stopped and locked until it has moved towards a depth of 1.36m from the point of contact with water surface. With this procedure, the overall efficiency of the equipment is improved by almost 20 per cent.

The removal of the utilized gross energy attenuates the waves so that the height of the out-going wave $H_p = \sqrt{1-\eta} \times H$. In the case of the waves of the example, $H_p = \sqrt{1-0.402} \times 4.5\,m = 3.48\,m$. Calculations concerning the efficiency of the equipment must be carried out in accordance with this lower height, i.e. the working height.

When the height of the pontoon construction is 2.5 m and the height of the working wave the said 3.48 m, the top level of the pontoon construction is now at the level $-1.74 - 1.36 + 2.5 = -0.6$ m. This level—the permitted advance of about 0.1 m is reached by the rising wave crest about 24° before the surface level, at which time the sensor 21 gives a releasing impulse to the locking means 9 and the rising stage begins. The wave's own rising movement thereat gives the pontoon construction an extra initial velocity, and as the hydrodynamic shape of its containers reduces the friction with an increasing velocity, the lifting force of the pontoon need hardly be much higher than the weight of the pontoon for the same final velocity to be reached. After the pontoon construction has made contact with the water surface, the sensor 14, by means of its impulse, eliminates the counter-pressure in the high-pressure fluid pumps 9, and the pontoon construction continues its rising and reaches the top height $1.74 + 1.36 = 3.1$ m (top face), being locked in this position. The height of its lower face above the average level of the water surface is thereat 0.6 m. When the rear face of the out-going wave crest reaches this level plus the permitted advance, the sensor 21 gives a releasing impulse to the locking mechanisms 9 and a new period starts.

Owing to its in itself large volume as well as to the considerable masses of water bound to it, the pontoon construction 1 has excellent possibilities of also utilizing the horizontal components of movement of the wave crest and the wave trough. This is achieved by braking the movement of the supporting carriage by means of single-acting high-pressure fluid pumps 19.

Owing to its low acceleration, at the beginning of its rising stage, when the rate of rising of the wave surface is already close to its maximum value, the pontoon construction remains remarkably deep below the surface. In order that the support structures of the pontoon do not slow down its rising movement at this stage, the containers of the pontoon must be provided with tubular fixing arms 4 whose length is 1/3 to 1/2 of the wave height H, depending on the period T of the chosen predominant average waves.

Correspondingly, at the beginning of the lowering stage, the bottom of the pontoon construction 1 remains remarkably high above the water surface. This is why the intermediate flanges 20, which are important in view of the utilization of the horizontally effective kinetic energy, have been lenghtened so that they extend by about one height of a container 3 below the bottom of the pontoon construction. By means of a slight bending of their bottom portions in the direction of the out-going wave, the overall output has been improved additionally to some extent.

For long ocean waves, T = 10 to 15 seconds, in an anchored version of the wave-energy conversion unit, the prolonged weight/lifting force of the pontoon construction gives the entire power-plant system a considerable acceleration. Thus, at the end of the lowering stage of the pontoon construction, the entire plant continues its movement downwards, and this movement does not end until it has been overruled by the lifting force of the pontoon construction approximately at the average surface level during the next rising stage. This movement, which may amount to several metres, is not detrimental as it increases the length of the useful movement towards the rising and the lowering stage, but when uncontrolled, it may cause resonance distrubances when losing its timing relative to the wave movement. This is why it is advisable to multiply the mass of the power plant construction by therein binding underlying water masses by means of substantially horizontal sheet planes, which are not shown, so that the mass in this way obtained is 10 to 20 times as large as the overall mass of the pontoon construction.

Thus, in the example case, the power yielding by the vertical movement of the pontoon construction is $2 \times 200{,}000 \times (0.6 + 1.74) \times 0.949 = 88{,}000$ kgm/10s/10m of wave front, i.e. 87.1 kWs/1 m of wave front, the efficiency 0.402 as calculated from the vertical component of the wave energy.

The share of the energy component effective horizontally in the overall energy varies from almost zero, in a long low roller, to almost one third, in short, steep storm waves. In the example waves, it is of the order of 12 to 15 %, as calculated on the basis of 13.5 %, 34 kWs. The pontoon construction with its long intermediate flanges binds a large water volume in itself and therefore reaches at least the same efficiency both from the horizontal and from the vertical energy component, and therefore, calculated on the basis of 0.402, yields 13.7 kWs/1 m of wave front. Thus, the gross output generated by the equipment would be 100.8 kWs/1 m of wavefront.

If, in the support construction, a second pontoon construction is installed after the first one, and is dimensioned for a lower wave height and is consequently lower, it is further possible to utilize 40 % of the residual wave, i.e. 59.7 kWs, whereby the overall output of the equipment is increased to 160.5 kWs/1 m of wave front, the efficiency being 0.642. The height of the out-going residual wave is thereby reduced to 2.69 metres.

The equipment herein described may be applied either mainly as a small-scale stationary or anchored wave-energy power plant as well as, for example, to oil drilling rigs if its horizontal pushing force is compensated.

The combination of pontoon construction and supporting carriage described above can be replaced by a pontoon construction which is connected by a long, vertically moving carrying arm to the frame of the power plant by the intermediate of an articulated joint that is resilient in the horizontal direction and that

can be locked.

CLAIMS

1. An energy conversion unit for a wave-energy power plant, comprising a frame and a conversion device movably attached to the frame for reacting to waves, wherein the conversion device comprises a supporting carriage arranged for movement horizontally relative to the frame a pontoon construction connected to the supporting carriage for movement along with the wave movement, locking means for locking the pontoon construction in the highest and lowest positions reached by it along with the wave in the vertical direction and for releasing it again after the wave crest/trough has moved forwards so that the pontoon construction is then almost completely above/below the water surface, and single-acting or double-acting high pressure fluid pumps connected to the pontoon construction, for converting the energy of the free movement of the pontoon construction to hydraulic pressure.

2. Energy conversion unit as claimed in claim 1, wherein the pontoon construction has a carrying part which comprises several vertical cylindrical containers shaped slightly hydrodynamically at both ends.

3. Energy conversion unit as claimed in claim 2, wherein detectors are connected to at least one of the containers for giving an impulse, on reaching contact with the water surface, for temporary elimination of the counter-pressure of the high-pressure fluid pumps in order to give the pontoon construction a residual acceleration.

4. Energy conversion unit as claimed in claim 2 or 3, wherein the mass of the pontoon construction is approximately one half or slightly less than one half of the mass of the quantity of water displaced by its containers.

5. Energy conversion unit as claimed in claim 2, 3 or 4 wherein the containers are located in the pontoon construction apart from each other, so that they permit movement of water in the vertical direction, whereas movement of water in the horizontal direction is prevented by intermediate flanges.

6. Energy conversion unit as claimed in claim 5, wherein the intermediate flanges extend by about one height of a container below the bottom of the pontoon construction and have their bottom portions bent slightly in the direction of the out-going wave.

7. Energy conversion unit as claimed in claim 2, wherein the containers are provided with tubular arms whose length is 1/3 to 1/2 of the height of the predominant average waves.

8. Energy conversion unit as claimed in claim 1, wherein for limiting the horizontal movement of the supporting carriage relative to the frame, single-acting pressure fluid pumps are fitted between the supporting carriage and the frame, the said pumps being attached at one end to the supporting carriage and at the other end to the frame.

9. Energy conversion unit for a wave-energy power plant substantially as hereinbefore described with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1984.
Published at the Patent Office, 25 Southampton Buildings, London WC2A 1AY, from which copies may be obtained.